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ABSTRACT OF THE DISCLOSURE

A multi-monopolar electrolytic cell assembly and system is provided. It includes two or more modular units, each being provided for throughflow of electrolyte and includes a plurality of parallel alternately spaced anodes and cathodes, i. e. having an inlet for the flow of electrolyte to, and between, the anodes and cathodes, and outlet means specially constructed and arranged to withdraw electrolyte and gaseous products of electrolysis entrained and/or occluded therein from the chamber. The chamber is electrically isolated from the electrodes. The end plates of each of the modular units are respectively an anode end plate and a cathode end plate. The electrodes project, preferably at right angles, from the end plates, but in staggered spaced-apart relation, so that each anode electrode (with the exception of the end ones) can be disposed between a pair of adjacent cathode electrodes and vice versa. The end plates are provided with either anode electrodes or cathode electrodes projecting, preferably at right angles, from one face. Between adjacent modular units are intermediate plates which are combined anode and cathode holding and current transmitting plates. The intermediate plates are provided both with anode electrodes projecting from one face and cathode electrodes projecting from the other face. In one variant, the intermediate plates are perforated to permit the throughflow of electrolyte and products of electrolysis from one modular unit to the next one.

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This invention relates to a modular monopolar electrolytic cell which is assembled as a multi-monopolar electrolytic cell assembly to provide a compact system for high production. It also relates to the complete electrolysis system which may be provided therefrom.

Monopolar electrolytic cells provided with metal anodes and metal cathodes for the production of alkali metal chlorates from alkali metal chlorides are now extremely well known. However, plants employing monopolar cells normally find it necessary to employ high amperage, about 20,000 to 150,000 amps, and low voltage which usually is expensive in capital cost for both power substation cost, bus bar cost and power losses by the current transmission losses. It is therefore manifest that it is desirable to provide a monopolar electric cell and system in which the voltage and amperage are optimized to provide high production for optimum capital cost.

An object of one aspect of this invention is to provide a modular monopolar electrolytic cell assembly provided with metal electrodes in which the conventional bus bar connections between cell units may be eliminated.

An object of another aspect of this invention is to provide such an assembly which offers high production output by the use of multiple such modular units.

An object of yet another aspect of this invention is the provision of such modular units in the assembly which are electrically connected in series so that the assembly will have a voltage equal to a unit voltage times number of such modular units.

An object of yet another aspect of this invention is the provision of such a system which makes it practical to employ a rectifier power substation which is economically optimized by designing for a desirable voltage : current ratio.

An object of yet another aspect of this invention is to provide such modular units assembled in such a way as to minimize the floor area compared to conventional units of such throughput.



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An object of still another aspect of this invention is to provide such modular units assembled in such a way as to minimize valving and piping requirements and to simplify control.

An object of a still further aspect of this invention is to provide such modular units assembled in such a way as to provide improved circulation of liquor due to gas lift and density differential.

By the present invention, in its broad aspects, a modular monopolar electrolytic cell unit is provided. It includes two or more modular units, each being a double open-ended, preferably cylindrical chamber, the chamber being electrically isolated from the electrodes within the chamber. In one variant of the invention, each such chamber is provided with circumferential inlet and outlet means for throughflow of electrolyte in a direction of flow parallel to, and between, adjacent, parallel alternately spaced anodes and cathodes. The outlet means are arranged to discharge the electrolyte as well as the gaseous product of electrolysis. One end plate of the modular units is an anode end plate and the opposite end plate is a cathode end plate. The anode end plate is disposed at, and seals, one open end, the anode end plate being provided with a plurality of spaced-apart anodes projecting from one face thereof into the chamber. Similarly, the cathode end plate is disposed at, and seals, the other open end, the cathode end plate being provided with a plurality of spaced-apart cathodes projecting from one face thereof into the chamber in staggered alternate relationship to the anode electrodes which also project into the same chamber. In this variant of the invention, if two or more such modular units are provided in lateral, side-by-side relationship, each two adjacent such units are provided with a common intermediate cathode-anode holding and current transmitting plate disposed at, and sealing, the adjacent open ends of two adjacent such cells. Such common plate is provided with a plurality of spaced-apart cathodes projecting from one face thereof into the main chamber in staggered alternate relationship to the anodes also projecting into the main chamber, and a plurality of spaced-apart anodes projecting from the other face thereof into the main chamber in staggered alternate relationship to the cathodes also

projecting into the main chamber. The anodes and cathodes do not occupy the entire cross-sectional area of the chamber in order to provide one or more non-electrolysis zones in the chamber.

In another variant of the invention, two or more such modular units are provided in vertically stacked relationship. The lowermost of the units is provided with inlet means, e. g. circumferential inlet means for an introduction of electrolyte. The uppermost of the units is provided with outlet means, e. g. radial outlet means for the removal of electrolyte and both dissolved and gaseous products of electrolysis. One end plate of the modular units is an anode end plate and the other end plate is a cathode end plate. The anode end plate is disposed at, and seals, one open end, the anode end plate being provided with a plurality of spaced-apart anodes projecting from one face thereof into the chamber. Similarly, the cathode end plate is disposed at, and seals, the other open end, the cathode end plate being provided with a plurality of spaced-apart cathodes projecting from one face thereof into the chamber in staggered alternate relationship to the anode electrodes which also project into the same chamber. Each two adjacent such units are provided with a common intermediate cathode-anode holding and current transmitting plate disposed at, and sealing, the adjacent open ends of two adjacent such cells. Such common plate is provided with a plurality of spaced-apart cathodes projecting from one face thereof into the main chamber in staggered alternate relationship to the anodes also projecting into the main chamber, and a plurality of spaced-apart anodes projecting from the other face thereof into the main chamber in staggered alternate relationship to the cathodes also projecting into the main chamber. The sealing provided is between the cell units and the exterior of the cell units. The adjacent cell units are interconnected by providing communicating apertures in the common holding plates. The current leakage is controlled by the cross-sectional area and length of the apertures. The anodes and cathodes occupying less than the entire cross-sectional area of the chamber to provide one or more non-electrolysis zones to provide internal liquor circulation zones.

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By another aspect of each of these variants of this invention, the main open-ended chamber is cylindrical. Each open end is thus provided with an angular flange and each end plate is secured to the open end by means engaging the angular flange, the means being clamped between a retaining ring and the end plate being secured to the open end, a gasket being disposed between the open end and the end plate. When more than two such units are used, each intermediate plate is disposed between adjacent modular units and simultaneously clamp the adjacent units together by spaced-apart means engaging the annular flanges, the means being clamped
10 between a pair of spaced-apart retaining rings and the intermediate plate being secured to the open ends of the adjacent modular units, a gasket being disposed between each open end and the intermediate plate.

The invention also provides in another of its variants the provision of any of the variants of electrolytic cell units described above in combination with a common upper reacting chamber, having liquor inlet means from the cells, a brine inlet and gas outlet, and a lower reacting chamber having a liquor outlet means to the cell, and finished product outlet. The cell assemblies direct effluent to the upper reacting chamber by gas lift and receive inlet from the lower reacting chamber. The two
20 chambers are interconnected by a common connecting conduit, preferably through a heat exchanger. The reacting chambers are provided with sufficient conduit piping to minimize current leakage.

Preferably, the combination includes a pair of such modular unit systems, each cell in each system including: an effluent liquor riser pipe leading to an upper portion of the upper reacting chamber; a liquor infeed riser leading from a lower portion of the lower reacting chamber; and including a common connecting conduit situated between the pair of modular unit systems, the conduit being provided with heat exchanger means.

30 In the accompanying drawings,

Figure 1 is an idealized side elevational view of a plurality of modular units of an aspect of this invention, assembled to provide a multi-monopolar electrolytic cell assembly as a horizontal unit;

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Figure 2 is an idealized central vertical section of the multi-monopolar electrolytic cell assembly of Figure 1;

Figure 3 is a side elevational view, rotated through 90° of the anode and cathode plates of the embodiment shown in Figure 2;

Figure 4 is a section along the line IV-IV of Figure 3;

Figure 5 is an idealized central longitudinal vertical sectional view of a plurality of modular units of another variant of this invention, assembled to provide a multi-monopolar electrolytic cell assembly as a vertical tower;

10 Figure 6 is an idealized side elevational view of a complete electrolyte system embodying the multi-monopolar electrolytic cell assembly of Figure 1; and

Figure 7 is an idealized cross-sectional view along the line VII-VII of the electrolysis system of Figure 6.

Turning now to Figures 1 and 2, it is seen that the multi-unit electrolytic cell system 10 includes a plurality, in this case 4, modular cell units 11. Structurally, each modular cell unit includes a cylindrical tube 12, open at each end 13, 14 and provided with aligned circumferential liquor inlet cylindrical nozzle 15 and liquor effluent cylindrical nozzle 16. The circumferential lip adjacent opening 13 is provided with an angular and annular flange 17, while the circumferential lip adjacent opening 14 is provided with an angular and annular flange 18. A monopolar end plate 19, in this case a cathode end plate, is secured to the tube 12 at open end 13 by means of annular retaining flange 20, which has an angular surface mating angular surface of flange 17, and retaining ring 21, all being held together with suitable tension, and with liquor tight and electrically non-conductive gasket 22 disposed at the open end 13, by means of bolt and nut combinations 23, passing through aligned apertures in retaining ring 21 and cathode end plate 19 respectively. An anode end plate 119 is of the same structure as cathode end plate 19 and may be secured at open end 13 in a similar manner.

A combined cathode-anode intermediate plate 24 is provided between adjacent modular units 11, and the means holding the plate 24 to the

adjacent units 11 also holds adjacent units 11 together. Thus, gasket 25 is placed at open end 14, an annular retaining flange 26 is placed in mating relation to flange 18, and retaining ring 27 is placed against annular retaining flange 26. Gasket 22, annular retaining flange 21, and retaining ring 23 are placed at open end 13 of the adjacent tube 12 of modular unit 11. Then, the sub-assembly is assembled by means of nut and bolt combinations 28 passing through aligned apertures in retaining rings 23, 27 and intermediate plate 24.

10 The main body or tube 12 of the modular electrolytic cell 11 is preferably formed of glass for several reasons, namely, that it is (i) chemically resistant; (ii) transparent; and (iii) electrically resistant. One alternative to using glass tube 12 is to use steel, but in this case, the tube 12 should be electrically connected to the cathodes for protection against corrosion. It is, of course, absolutely essential that tube 12 be electrically isolated from the anodes, e. g. by gaskets and spacers. Another alternative is to make the tubes of titanium, which is chemically resistant to the liquor and does not require cathodic protection. To avoid the need for cathodic protection, the voltage potential is controlled to under 6 volts for current flow from the container. As shown, it is pre-
20 ferred to have a multi-unit assembly 10 comprising many units. e. g., one plant is designed for 12 units in one assembly.

Turning now to Figures 2, 3 and 4, it is seen that the intermediate plate is provided with a plurality of anode plates 29 on one face 30 thereof and a plurality of cathode plates 31 on the opposite face 32 thereof. Plate 24 may be a composite plate, e. g. one side steel to provide face 32 for the cathode electrodes 31, the other side titanium with noble metal of the platinum group or its oxides coating to provide face 30 for the anode electrodes 29. Such composite plates are commercially available, e. g. from Du Pont, under the Trade Mark "DETA-CLAD".

30 The electrodes may be welded to the holding plate or connected as shown in G.A.E. Cook's Canadian Patent Application Serial No. 081,531 filed April 30, 1970. As clearly seen in Figure 2, the anode and cathode electrodes 29, 31 respectively are offset to fit precisely in between each

other when assembled to an adjacent unit. The interelectrode space varies between 2 and 10 mm. It is noted from Figure 4 that the electrodes 31 do not cover the entire cross-sectional area of the cell container. A non-electrolysis zone 33 at each lateral end of the electrodes 31 is thus provided for the purpose of increasing circulation within the cell. The end plates 19 are, of course, either an anode or a cathode, but would have the same construction features as the intermediate electrode assembly.

Another variant of the invention is shown schematically in Figure 5. The multi-unit electrolytic cell system 110 is a vertical tower of a plurality, in this case nine, cells or compartments 111. The number of such compartments may, however, be as few as two, or as many as fifty. Each shell of the cell or compartment 111 is a cylindrical tube 112 formed, for example, of plastics material, e. g. polyvinyl chloride, polystyrene, etc. or glass.

Structurally, then, each modular cell unit or compartment 111 includes a cylindrical tube 112, open at each end 113, 114. The circumferential lip adjacent opening 113 is provided with an angular and annular flange 117, while the circumferential lip adjacent opening 114 is provided with an angular and annular flange 118. A monopolar end plate 119, in this case a cathode end plate, is secured to the tube 112 at open end 113 by means of annular retaining flange 120, which has an angular surface mating angular surface of flange 117, and retaining ring 121, all being held together with suitable tension, and with liquor tight and electrically non-conductive gasket 122 disposed at the open end 113, by means of bolt and nut combinations 123, passing through aligned apertures in retaining ring 121 and cathode end plate 119 respectively. The anode end plate 1191 is similar in structure to the cathode end plate 191 and may be secured to open end 113 in a similar fashion.

A combined cathode-anode intermediate plate 124 is provided between adjacent modular units 111, and the means holding the plate 124 to the adjacent units 111 also holds adjacent units 111 together. Thus, gasket 125 is placed at open end 114, an annular retaining flange 126 is placed in mating relation to flange 118, and retaining ring 127 is placed

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against annular retaining flange 126. Gasket 122, annular retaining flange 121, and retaining ring 123 are placed at open end 113 of the adjacent tube 112 of modular unit 111. Then, the sub-assembly is assembled by means of nut and bolt combinations 128 passing through aligned

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apertures in retaining rings 123, 127 and intermediate plate 124.

As described hereinbefore with reference to Figures 1 - 4, the main body or tube 112 of the modular electrolytic cell 111 is preferably formed of glass for several reasons, namely, that it is (i) chemically resistant; (ii) transparent; and (iii) electrically resistant. One alternative to using glass tube 112 is to use steel, but in this case, the tube 112 should be electrically connected to the cathodes for protection against corrosion. It is, of course, absolutely essential that tube 112 be electrically isolated from the anodes, e.g. by gaskets and spacers. Another alternative is to make the tubes of titanium, which is chemically resistant to the liquor and does not require cathodic protection. To avoid the need for cathodic protection, the voltage potential is controlled to under 6 volts for current flow from the container. As shown, it is preferred to have a multi-unit assembly 110 comprising many units, e.g., one plant is designed for twelve units in one assembly.

The intermediate plate 124 is provided with a plurality of anode plates 129 on one face thereof and a plurality of cathode plates 131 on the opposite face thereof. Plate 124 may be a composite plate, e.g. one side steel to provide the face for the cathode electrodes 131, the other side titanium with noble metal of the platinum group or its oxides coating to provide the face for the anode electrodes 129. Such composite plates are commercially available, e.g. from Du Pont, under the Trade Mark "DETAFLAD".

The electrodes may be welded to the holding plate or connected as shown in G.A.E. Cook's Canadian Patent Application Serial No. 081,531 filed April 30, 1970. The anode and cathode electrodes 129, 131 respectively are offset to fit precisely in between each other when assembled to an adjacent unit. The interelectrode space 134 varies between 2 and 10 mm. The end plates 119 are, of course, either an anode or a cathode, but would have the same construction features as the intermediate electrode assembly.

It is seen that the lowermost unit of the plurality of stacked

units 111 includes a circumferential liquor inlet nozzle 115, and the uppermost unit of the plurality of stacked units 111 includes an axial product outlet 116, carrying liquor and evolved gas which is entrained and/or occluded within the liquor.

It is also seen that the holding plates 124 are provided with perforations 130 thereby to channel the reactant liquor and the products of the reaction from the bottommost unit to the uppermost unit. The arrows 132 show the flow of the reactant liquor and the product through the plate 124 or an insert in the plate 124.

10 It will be observed that there is a non-electrolytic space 133. Assuming the electrodes 129, 130 do not seal tightly to the container 112, i.e. communicate with side sections and that there is a significant pressure drop for flow through the openings 130 in the holding plate 124, there will be a significant internal circulation between the side sections or non-electrolytic spaces 133 and the space 134 between electrodes.

 It is seen that the assembly in Figure 5 is basically the same as the assembly of Figures 1 and 2 earlier described. However, it will be noted that the flow through the assembly is longitudinally there-
20 through. Preferably all of the liquor to the assembly is fed to the lowest unit in the assembly through inlet nozzle 115 and liquor and gas are channelled from one unit to the other, preferably by openings 130 in the electrode holding plates 124 and finally discharged to a reactor from the top unit through outlet nozzle 116. The current leakage is controlled by cross-sectional area of the openings 130 in the plate 124 and the thickness of electrode holding plate 124. While not shown, the apertures 130 may be provided with hollow cylindrical inserts for annealing the effluent liquor and product gases. Then, the current leakage would be governed by the cross-sectional area of the hollow cylindrical inserts
30 and the length of such inserts.

 The main advantages of such vertical assembly compared to the horizontal assembly include the following, namely: (1) the floor area

requirement is drastically reduced; (2) one inlet for the liquor and one outlet for the product for each assembly is possible, thus minimizing valving and piping requirements and simplifying control; and (3) the assembly works essentially as a column containing a product of significantly lower density than the liquor feed; thus, the gas lift as well as the density differential cooperate in improving the circulation of liquor through the assembly.

It is also noted that the electrodes 129, 131 do not normally cover the entire cross-sectional area of the cell container. Thus, the design incorporates internal circulation. This is an especially important feature of the design when the assembly is erected vertically, since the internal liquor circulation resulting from the gas evolution on the electrode surface provides for interchange of electrolyte between the electrodes and standardizes conditions in the cell chambers.

While not shown in detail, the vertical assembly design may be designed to make the column size sufficiently large to provide mainly by means of non-electrolytic spaces 133 in the compartment the total desirable electrolyte volume and retention time for chemical reactions to chlorate. In this case, no external recirculation would be required.

20. This is very desirable in some aspects since it minimizes piping requirements and provides cascade arrangement between compartments, or cells, under favourable conditions. Thus, electrolyte (brine) enters at the lowest compartment and finished product leaves at the top compartment, the retention time being provided in each and every compartment. This construction provides the conditions for conversion of hypochlorite to chlorate in each compartment. Temperature control could be maintained by, for example, installing a cooling coil in the compartments or jacketing the columns. On the other hand, with the variant of Figures 1 and 2, a separate cell assembly may be installed indoors and the

30 reactors outdoors.

The electrode assembly may be fitted inside a large tube (e.g. a glass column) rather than dividing the column into sections. The

electrode holding plates would then be placed between sections.

While the assembly has been shown vertical, it may be inclined to various degrees up to and including vertical installation, i.e., from 0 to 90° relative to the horizontal.

Turning now to Figures 6 and 7, it is seen that a pair of multi-monopolar electrolytic cell assembly and system 10 is disposed between and interconnected to an upper reaction chamber 36 and a lower reaction chamber 37 to provide an electrolysis system 35. Each outlet nozzle 15 is connected to an effluent riser pipe 38, each riser pipe extending upwardly within upper reaction chamber 36 to terminate near the top thereof at outlet 39. Entrained and/or occluded gases formed during the electrolysis reaction are permitted to separate from the liquor 40 and to pass upwardly into a gas chamber 41 provided with a frangible cover 42 (for safety reasons) and with a gas outlet nozzle 43 leading away from the electrolysis system. Fresh brine is introduced through cylindrical inlet nozzle 44 which extends downwardly into the upper reaction chamber 36 to terminate in a submerged outlet 45.

Degassed liquor in which the reaction to chlorate has been at least partially completed passes through a common connecting conduit 46 disposed between the pair of multi-unit cell systems 10 and passes through an annular heat exchanger 47 having cooling water inlet 48 and water effluent 49. If desired, the heat exchanger may be cooling coils disposed in the lower reaction chamber 37, or any other suitable means. From the lower reacting chamber, an inlet riser pipe 50, connected to each inlet nozzle 14 of cell 11 originates at an inlet 51 near the bottom of chamber 37 and brings liquor 53 from lower reacting chamber 37 to cells 11. Finished product chlorate is withdrawn from outlet nozzle 54 at the bottom of chamber 37 and passes via outflow conduit 55 leading to chlorate storage (not shown).

During the course of the electrolysis, gases produced are in the liquor in the form of entrained or occluded bubbles. This reduces the density of the liquor to such an extent that the effluent liquor is

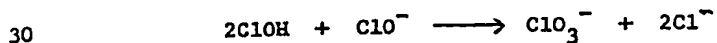
pumped, by gas lift, up effluent riser pipes 38 and is sucked upwardly through inlet riser pipes 50. The pipe risers 38 and 50 provide sufficient piping to minimize current leakage.

In the example where the cells 11 are used for chlorate electrolysis, the electrolyte is brine and the electrolytic products are: hypochlorite, chlorate and hydrogen gas, as well as by-product oxygen and water vapor.

Since the electrolysis is of sodium chloride brine with no diaphragm, the effluent, consisting of Cl_2 , Na^+ , H_2 , OH^- , ClOH , Cl^- , H^+ , and OCl^- and in the form both of liquor and gaseous products, pass from effluent pipe risers 38 to upper reacting chamber 36. The level of the liquor 40 in upper reacting chamber 36 is shown by level line 57 and is higher than outlets 39 so that liquor and gaseous products are separated from one another. The upper portion of the upper reacting chamber 36 consequently acts as a degasifier. Recycle liquor passes down through upper reacting chamber 36 through common conduit 46 to lower reacting chamber 37.

The liquor velocity through upper reacting chamber 36 is reduced to such an extent that optimum separation of the entrained gases takes place without short-circuiting through the tank, which would result from too low a liquor velocity. The velocity, on the other hand, must be sufficient to utilize the entire vessel but not too rapid to inhibit the expulsion of any further entrained and/or occluded product gases. The optimum velocity is a function of the apparent density of the liquid, which, in turn, is dependent on the amount of entrained gases and the bubble size. It has been found that a liquor velocity of about 10 ft/min. can separate substantially 100% of the entrapped gases.

Upper reacting chamber 36 and lower reacting chamber 37 combined are for the purpose of permitting the reaction



to take place. For any selected temperature, the retention time in reacting chambers 36, 37 is a function of the concentration of ClOH and

ClO^- present in the liquor which in turn is directly related to the current density. Thus, it was found that to yield a current efficiency of greater than 90%, with a constant recirculation of liquor and a pH of approximately 6.5, the current concentration should be less than 7 amps/litre at 80°C. or less than 6 amps/litre at 60°C. The current concentration (in amps/litre) is the main determining factor in calculating the reacting chamber volume. The retention time, on the other hand, is dependent on the rate of the liquor circulation, as well as on the volume of the reaction vessel.

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The liquor entering the upper reacting chamber 36 may have temperatures ranging from about 45°C. to 100°C., preferably between about 60 and 80°C. Figures 6 and 7 show a heat exchanger 47 which is provided for temperature control. The reacting chamber parameters are such that there is a sufficiently long retention time of liquor in reacting chambers 36, 37 to favour the desirable reaction $\text{NaOCl} + 2\text{HClO} \longrightarrow \text{NaClO}_3 + 2\text{HCl}$.

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It is also important to minimize the concentration of the hypochlorite for if it is too high, it will decompose and anode electrode coating wear increases. In addition, the pH should be maintained below 7.5 and preferably between about 5 and 7. At a pH of 6.8, the optimum reaction of two moles of HClO to 1 mole of NaOCl takes place if no dichromate is present.

Effluent from the lower reacting chamber 37 is conveyed to cells 11 through inlet pipe riser 50 to inlet nozzle 14. Gas is drawn off at outlet 43 from gas chamber 41. Gases, consisting of H_2 , H_2O (vapor), O_2 , CO_2 and Cl_2 may be vented as waste through outlet 43 or may be utilized.

If it is desired to utilize the gases from outlet 43 by oxidizing them, it is noted that the gases have the following ranges of proportions:

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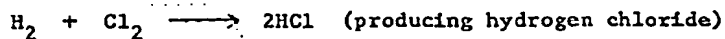
Hydrogen, H_2	86 - 94	% by volume
Water vapor, H_2O	3 - 10	"

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Oxygen, O_2 1 - 4 % by volume

Chlorine, Cl_2 0.1 - 1 "

In combusting the gases the following reactions will take place;



The hydrogen chloride may be recovered as hydrochloric acid by scrubbing with water.

10 It is generally known that the oxygen content of the cell gas decreases with a lower pH of the electrolyte simultaneously as the chlorine losses increase. Using a combustion chamber for the recovery of chlorine losses as hydrochloric acid, the cell may be operated at a low pH and thus benefit by the resulting improved current efficiency.

Thus, it should be pointed out that the cell apparatus may be used employing forced circulation. The process system hereinabove discussed utilizes the gaseous products as a means to create a lift in the external pipe riser and thus does not require any means for forced circulation.

20 In the above-described assembly containing the cells 11, gases produced in the cell assemblies 11 rise in the pipe riser and thus cause recirculation of liquor. Two reactors are preferred, but the cell assemblies may also be used with a system employing one reactor only. An external heat exchanger is desirable for easy maintenance and to achieve a high U-value by the higher velocity compared to a heat exchanger (or coil) which may be placed inside the upper reacting chamber 36.

Current flow is from one end of the cell assembly through first unit anode electrodes 19 via the cell electrolyte space to the cathode electrodes of the intermediate holding plate 24 and then into the second unit and so on until the current leaves at the opposite end of the electrode assembly.

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The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In an electrolysis apparatus, a modular monopolar electrolytic cell comprising:

- (a) an open-ended main chamber including inlet means for the flow of electrolyte to, and between, adjacent, parallel, alternately spaced anodes and cathodes and outlet means constructed and arranged to withdraw electrolyte along with gaseous products of electrolysis entrained and/or occluded therein from the chamber, said main chamber being electrically isolated from said anodes and cathodes;
- (b) an anode end plate disposed at, and sealing, one open end thereof, the anode end plate being provided with a plurality of spaced-apart anodes projecting from one face thereof into said main chamber;
- (c) a cathode end plate disposed at, and sealing, the other open end, the cathode end plate being provided with a plurality of spaced-apart cathodes projecting from one face thereof into said main chamber in staggered alternate relationship to the anode also projecting into said main chamber;

said anodes and cathodes occupying less than the entire cross-sectional area of the main chamber thereby to provide at least one non-electrolysis zone within said cell, thereby to enable internal liquor circulation resulting from gases evolved on the electrode surfaces to interchange electrolyte between the electrodes and to provide substantially homogeneous conditions in the cell chamber.

2. The apparatus of claim 1 wherein, in said modular monopolar electrolytic cell, said inlet means is circumferential and said outlet means is circumferential, whereby electrolyte flows circumferentially into the cell, flows across the cell from circumference to circumference and electrolyte and gaseous products of electrolysis are removed circumferentially.

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3. The apparatus of claim 1 wherein, in said modular monopolar electrolytic cell, said inlet means is circumferential and said outlet means is axial, whereby electrolyte flows circumferentially into the cell, electrolyte and gaseous products of electrolysis flow longitudinally through the cell and electrolyte and gaseous products of electrolysis are removed axially.

4. An electrolysis apparatus comprising at least two modular monopolar electrolytic cells as claimed in claim 2, disposed horizontally in lateral end-to-end relationship, thereby to provide a multi-monopolar electrolytic cell assembly, each two adjacent such cells being provided with:

- (d) a common intermediate cathode-anode holding and current transmitting plate disposed at, and sealing the adjacent open ends of two adjacent such cells, and being provided with a plurality of spaced-apart cathodes projecting from one face thereof into said main chamber in staggered alternate relationship to the anodes also projecting into said main chamber, and a plurality of spaced-apart anodes projecting from the other face thereof into said main chamber in staggered alternate relationship to the cathodes also projecting into said main chamber.

5. An electrolysis apparatus comprising one modular monopolar electrolytic cell as claimed in claim 3 and at least one modular monopolar electrolytic cell including (a) an open-ended main chamber including axial inlet means for the flow of electrolyte to, and between, adjacent, parallel, alternately spaced anodes and cathodes and axial outlet means constructed and arranged to withdraw electrolyte along with gaseous products of electrolysis entrained and/or occluded therein from the chamber, said main chamber being electrically isolated from said anodes and cathodes; (b) an anode end plate disposed at, and sealing, one open end thereof, the anode end plate being provided with a plurality of spaced-apart anodes projecting from one face thereof into said main chamber; and (c) a cathode end plate disposed at, and sealing, the other open end, the cathode end plate being provided with a plurality of spaced-apart cathodes projecting from one face thereof into said main chamber in staggered alternate relationship to the anode also projecting

into said main chamber; said anodes and cathodes occupying less than the entire cross-sectional area of the main chamber thereby to provide at least one non-electrolysis zone within said cell, thereby to enable internal liquor circulation resulting from gases evolved on the electrode surfaces to interchange electrolyte between the electrodes and to provide substantially homogeneous conditions in the cell chamber, in vertically stacked, end-to-end relationship, thereby to provide a multi-monopolar electrolytic cell assembly, each two adjacent such cells being provided with:

- (d) a common intermediate cathode-anode holding and current transmitting plate disposed at, and sealing the adjacent open ends of two adjacent such cells, and being provided with a plurality of spaced-apart cathodes projecting from one face thereof into the main chamber of each said modular monopolar electrolytic cell in staggered alternate relationship to the anodes also projecting into said main chambers, and a plurality of spaced-apart anodes projecting from the other face thereof into the main chamber of each said modular monopolar electrolytic cell in staggered alternate relationship to the cathodes also projecting into said main chambers wherein said holding plate includes axially extending perforations therethrough between projecting electrodes, thereby to provide flow of electrolyte into the lowermost cell, flow of electrolyte ~~and~~ and gaseous products of electrolysis from the bottom of the assembly to the top of the assembly to be discharged axially from the top, and to provide for throughflow of electrolyte and gaseous products of electrolysis from one cell to an adjacent cell disposed at a higher level.

6. The electrolysis apparatus of claims 1, 2 or 4 wherein the main open-ended chamber is cylindrical, wherein each open end is provided with an angular flange and wherein each end plate or holding plate is secured to the open end by means engaging the angular flange, said means being clamped between a retaining ring and the end plate being secured to the open end, a gasket being disposed between the open end and the end plate or the holding plate.

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7. The electrolysis apparatus of claims 3 or 5 wherein the main open-ended chamber is cylindrical, wherein each open end is provided with an angular flange and wherein each end plate or holding plate is secured to the open end by means engaging the angular flange, said means being clamped between a retaining ring and the end plate being secured to the open end, a gasket being disposed between the open end and the end plate, and a perforated gasket having apertures aligned with the apertures in the holding plate being disposed between the open end and the holding plate.

8. The electrolysis apparatus of claim 2 disposed at an angle of 0° to 90° to the horizontal.

9. The electrolysis apparatus of claims 5 or 8 wherein the apertures in the holding plates are provided with hollow cylindrical inserts.

10. The electrolysis apparatus of claims 1, 4 or 5 wherein said non-electrolytic zone is sufficiently large to provide the necessary electrolyte volume and retention time for chemical conversion of products of electrolysis to chlorate.

11. The electrolysis apparatus of claims 1, 4 or 5 including temperature control means associated with each modular unit.

12. The electrolysis apparatus of claims 1, 4 or 5 including temperature control means comprising a cooling coil in the modular units.

13. The electrolysis apparatus of claims 1, 4 or 5 including temperature control means comprising a cooling coil jacketed around the entire column.

14. The electrolysis apparatus of claims 4 or 5 wherein said main chamber is provided by elongated tubes containing holding plates therein and end plates.

15. The electrolysis apparatus of claims 1, 4 or 5 wherein the main chamber is formed of glass tubes.

16. The electrolysis apparatus of claims 1, 4 or 5 wherein the main chamber is formed of titanium tubes.

17. The electrolysis apparatus of claims 1, 4 or 5 wherein the main chamber is formed of steel tubes.

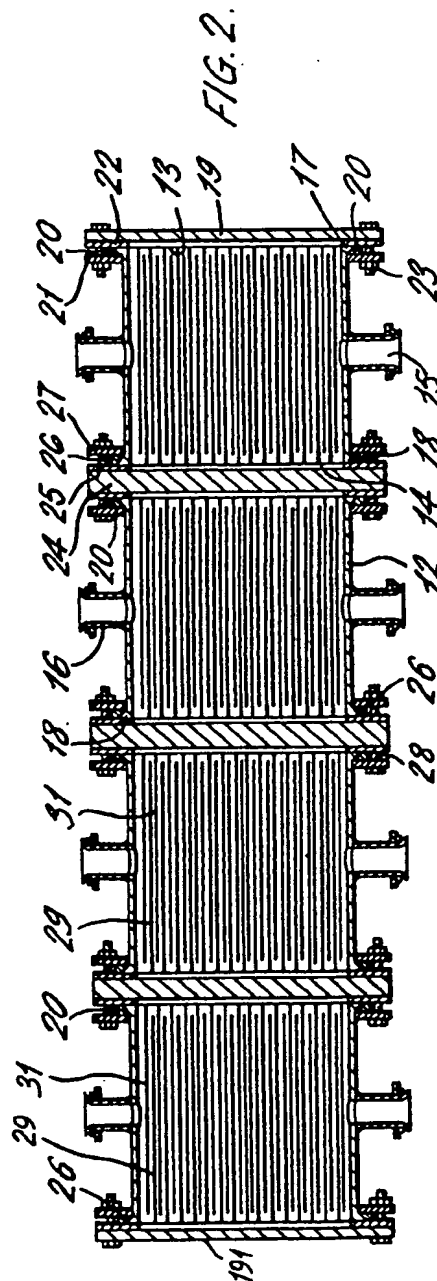
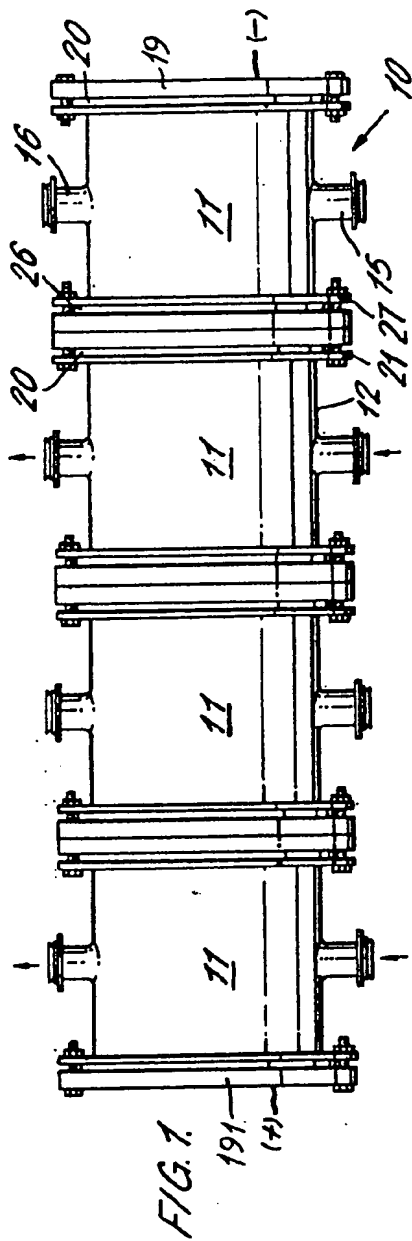
18. The electrolysis apparatus of claims 1, 4 or 5 wherein the anode plate and the anode are formed of titanium bearing a surface coating of a noble metal of the platinum group or oxides of such metal, and wherein the cathode plate and the cathode are formed of steel.

19. An electrolysis assembly comprising the combination of the electrolysis apparatus of claims 4 or 5 with a common upper reacting chamber, having a liquor inlet connected to said cells; a brine inlet and a gas outlet; a common lower reacting chamber having a liquor

inlet, a liquor outlet connected to said cells to feed said cells and a finished product outlet; and a common conduit interconnecting the upper reacting chamber and the lower reacting chamber; the circulation between cells, upper reacting chamber and lower reacting chamber being by means of gas lift.

20. An electrolysis assembly comprising the combination of the electrolysis apparatus of claims 4 or 5 with a common upper reacting chamber, having a liquor inlet connected to said cells; a brine inlet and a gas outlet; a common lower reacting chamber having a liquor inlet, a liquor outlet connected to said cells to feed said cells and a finished product outlet; and a common conduit interconnecting the upper reacting chamber and the lower reacting chamber; the circulation between cells, upper reacting chamber and lower reacting chamber being by means of gas lift, and further including a pair of said modular unit systems, each cell in each system including: an effluent liquor riser pipe leading to an upper portion of the upper reacting chamber; a liquor infeed riser leading from a lower portion of the lower reacting chamber; and including a common connecting conduit situated between the pair of modular unit systems, the conduit being provided with heat exchanger means.

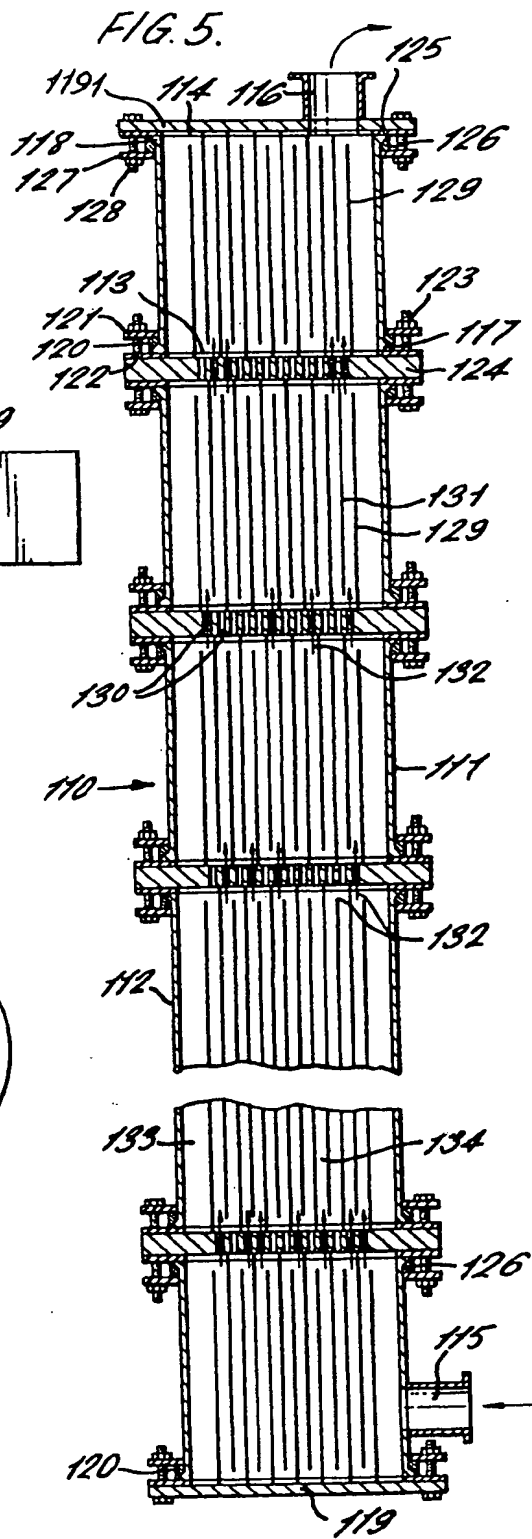
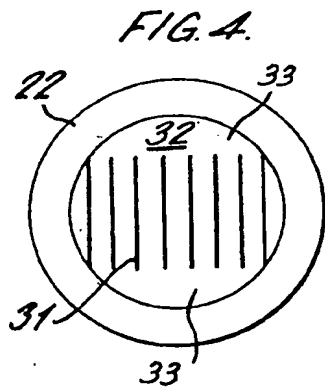
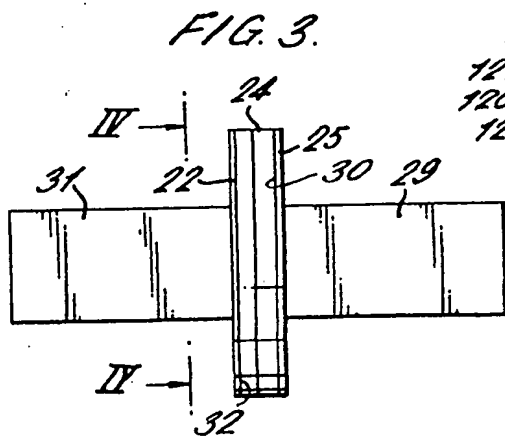




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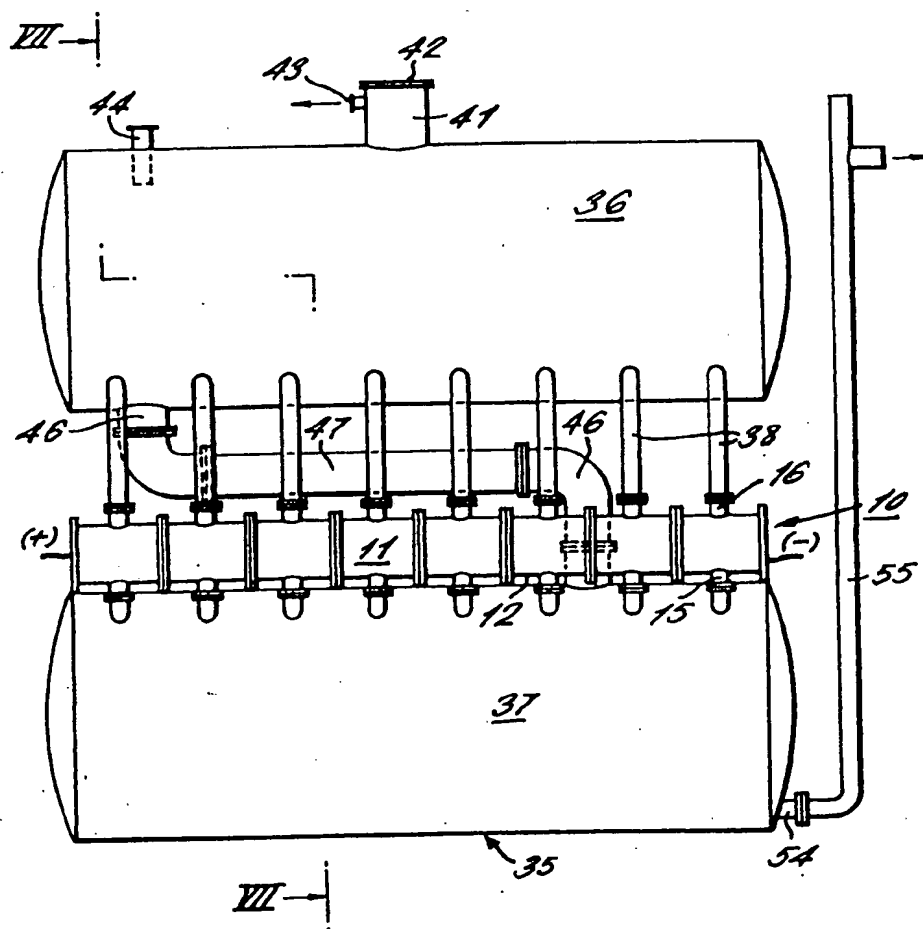
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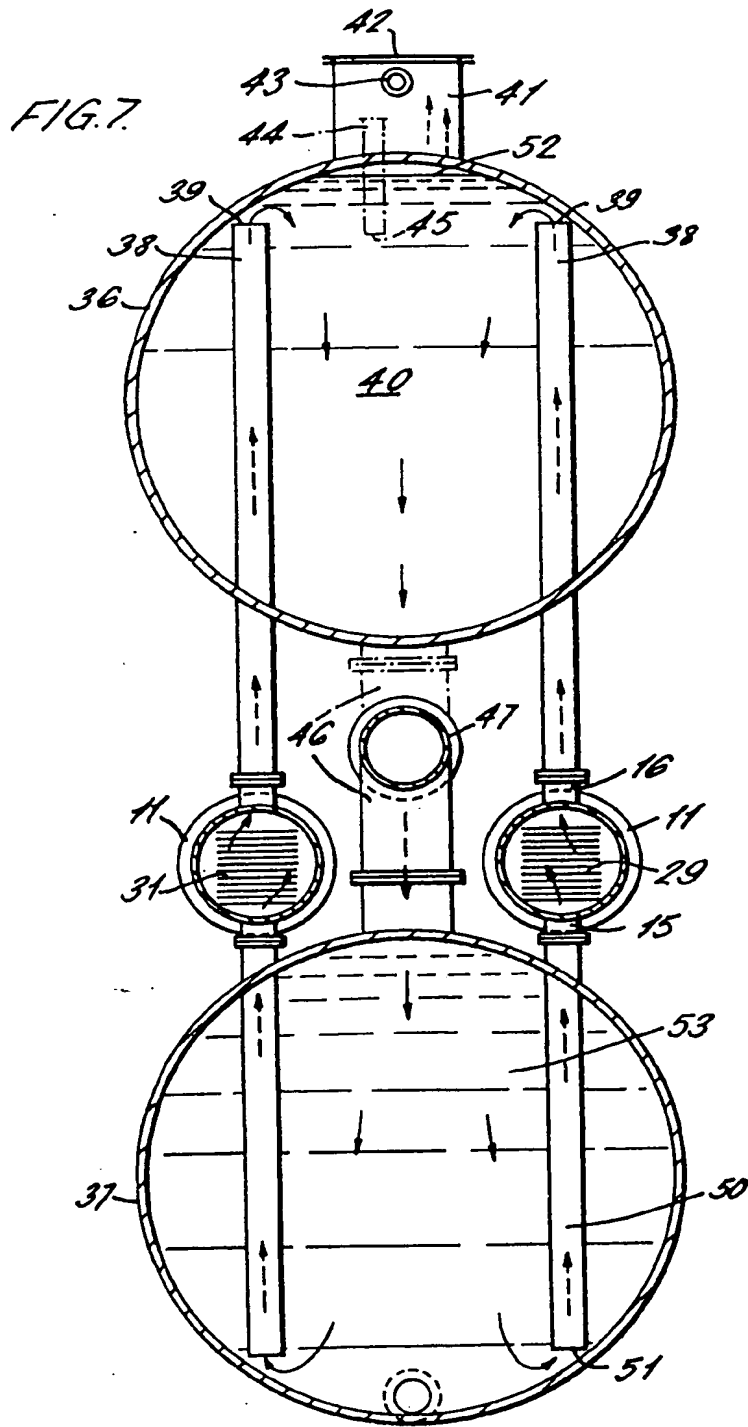
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FIG. 6.



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